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OPTIMIZATION OF MACHINING PARAMETRIC STUDY ON ELECTRICAL DISCHARGE MACHINING (EDM)

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Abstract— *In Present Scenario, Productivity and quality are two important aspects that have become great concerns in today's competitive global market. Every production/manufacturing unit mainly focuses on these areas in relation to the process, as well as the product developed. The electrical discharge machining (EDM) process, even now it is an experience process, wherein the selected parameters are still often far from the maximum, and at the same time selecting optimization parameters is costly and time consuming. Material Removal Rate (MRR) during the process has been considered as a productivity estimate with the aim to maximize it, with an intention of minimizing surface roughness taken as most important output parameter. These two opposites in nature requirements have been simultaneously satisfied by selecting an optimal process environment (optimal parameter setting). Objective function is obtained by Regression Analysis and Analysis of Variance. Then objective function is optimized using Genetic Algorithm technique. The model is shown to be effective; MRR and Surface Roughness improved using optimized machining parameters.*

Keywords— Material Removal Rate (MRR); Tool Wear Rate (TWR); OC; DOE; ANOVA; MINITAB

1. INTRODUCTION

NON-TRADITIONAL machining has been got well out of the need to machine this material. The machining processes are non-conventional in the sense that they do not employ traditional tools for metal removal, but they directly use other forms of energy. The problems of high complexity in size, shape and higher demand for product accuracy and surface finish can be solved through non-traditional methods. EDM has been replacing grinding, milling, drilling and another traditional machining.

EDM has additionally made its quality felt in new fields, for example, therapeutic, sports and surgical, optical, instruments, including car R&D ranges. Since EDM was created, much hypothetical and exploratory work has been done to distinguish the fundamental procedures included. It is currently one of the fundamental strategies utilized as a part beyond words and has great exactness and accuracy with no direct physical contact between the cathodes so no mechanical anxiety is applied on the work piece. The essential yield parameters of the procedure are the MRR, device wear proportion (TWR) and surface harshness (unpleasantness normal). Streamlining of the EDM procedure is worried about boosting MRR while limiting TWR [1].

The EDM procedure enhancement utilizing tungsten–copper electrodes, and diagrams another two-organize preparing technique, which gives a critical change in general execution. In the new two-organize technique, a black layer altered surface is created on the apparatus in the primary stage which instrument wear, in this way giving better device wear for a given material expulsion rate in the second stage [2]. Amid the EDM procedure, both the apparatus and work piece experience surface change. Numerous scientists have taken a gander at alteration of the work piece, however few have analyzed change of the device. The relocation of components from the work piece to the device cathode happens utilizing both high and low current powers. A few specialists, utilizing tungsten-copper (80/20) terminals and an IS-T215 Cr12 steel work piece, likewise demonstrated that iron and chromium moved from the work piece to the instrument anode. A few creators have asserted that the vast majority of the anode wear is because of vanishing and combination; in any case, they brought up that the EDM material evacuation is caused by savage ejection of the superheated cathode softens from the liquefy cavities toward the finish of the machine beat.

Improvement is worried about amplifying the material evacuation rate, limiting the instrument wear proportion and getting a decent surface wrap up. There are many info parameters which can be changed in the EDM procedure which affects the EDM execution attributes. A versatile control framework that improves settings on the web, for instance, servo reference voltage, beat span, beat interim and dielectric stream rate.

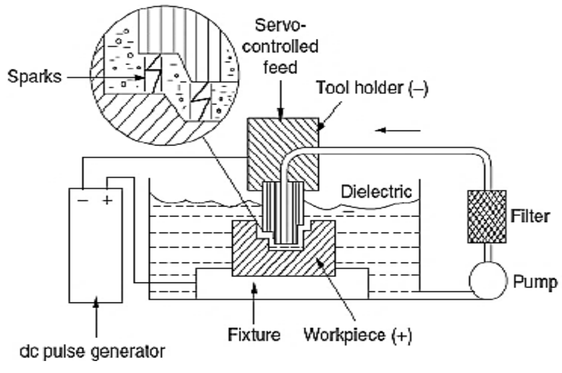

Fig. 1. EDM Setup

2. EDM PRINCIPL

Due to erosion caused by rapidly recurring spark discharge, which is taking place between the tool and work piece, metal is removed in this process. A thin gap of about 0.025mm is maintained between the work pieces and the tool by a servo system, as shown in Fig. 1. Both the work piece and tool are merged in a dielectric fluid like EDM oil/kerosene/de-ionized water. The work piece is anode and tools the cathode. In an interval of about 10 microseconds voltage across the gap becomes sufficiently large to discharge a spark. Electrons and positive ions accelerate creating a discharge channel that becomes conductive. It is at this point when the spark causing collisions between the electrons and ions are creating a channel of plasma. Electrical resistance suddenly drops off and the previous channel allows that current density reach very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment the spark occurs sufficiently, the pressure developed between the tool and work piece, due to the high temperature, is reached and the metal is eroded at that high temperature and pressure.

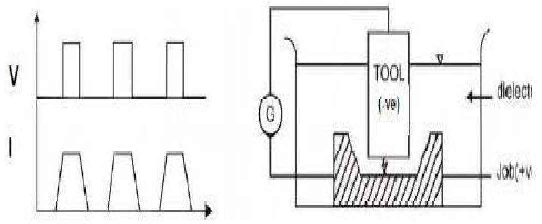

Fig. 2. Working Principle of EDM Process

Material removal occurs due to such extreme localized temperature, because of the moment vaporization of the material, and additionally because of liquefying material evacuation that happens. Molten metal is not completely removed but only partially. The plasma channel is never again maintained, as the potential contrast is pulled back, as appeared in Fig. 2. It generates shock or pressure waves, which evacuates the molten material forming a crater of removed material all around the region of the spark, as the plasma breakdown.

3. EDM PARAMETRS

A. Spark On-time (Pulse Time or T_{on})

Spark on-time is the duration of time (µs) that current is allowed to flow per cycle. MRR (Material Removal Rate) varies directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and length of the on-time.

B. Spark Off-time (Pulse Time or T_{off})

This time enables the molten material to solidify and to be washed out of the arc gap. This parameter affects the speed and the dependability of the cut. If the off-time is too short, it creates an unstable spark.

C. Arc Gap

It is the distance between the electrode and the work piece during the process of EDM. It might be called as the spark gap. The spark gap can be handled by the servo system.

D. Discharge Current (Current Ip)

The current is measured in ampere allowed per cycle. Discharge current directly proportional to the Material removal rate (MRR).

E. Duty Cycle (τ)

It is a percentage of the on-time relative to the total cycle time. This Parameter is measured by dividing the on-time by the total cycle time (on-time pulse off time).

$$\tau = \frac{T_{on}}{T_{on}+T_{off}} \tag{1}$$

F. Voltag (V)

It is a potential that can be measured as volt, it also affects the MMR and allowed per cycle. Voltage is given as 50 V in this experiment.

G. Diameter of Electrode (D)

There are two different sizes of 4mm and 6mm diameter in this experiment. This tool is used as an electrode and also for internal flushing.

H. Dielectric Fluid

In EDM, as has been discussed about before, material removal occurs mainly due to melting and thermal evaporation. Thermal processing is required to be carried out in the absence of oxygen so that the process can be controlled and its oxidation is avoided. Frequently oxidation prompts poor surface conductivity (electrical) of the work piece further machining. Hence, dielectric fluid should provide an oxygen free machining environment and at the same time it should have enough strong dielectric resistance so that electrically it doesn't breakdown too easily, while at the same time ionize when electrons collide with its molecule. Moreover, it should be thermally resistant during sparking as well.

The metal removal rate, electrode wear rate and other operation qualities are additionally affected by the dielectric liquid. The general dielectric fluids used are transformer on silicon oil, kerosene (paraffin oil), EDM oil and de-ionized water are used as dielectric fluid in EDM. The dielectric medium is generally passed forcing around the spark zone and also applied through the tool to achieve efficient removal of molten material.

I. Fliushing Method

Flushing is an important function in any electrical discharge machining operation. It is the process of introducing clean filtered dielectric fluid into the spark gap.

J. Tool Material

High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating. High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear. Higher density – for the same heat load and same tool wear by

weight, there would be less tool wear or volume removal and thus less dimensional loss or inaccuracy. High melting point – Since EDM is a thermal process, it would be logical to assume that the higher the melting point of the electrode material, the better the wear ratio will be between electrode and work piece material.
Different types of tool material are being used in the EDM method and the tool steel contains alloy and carbon steels that are particularly well-suited to be made into tools. The edge temperature under expected use is an important determinant of both the required heat treatment and composition. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc.

In this experiment, we have utilized Ni-Cr-Co as a work piece material.

K. Work piece Specification

TABLE I. WORKPIECE MATERIAL

Sr. No.	Ni-Cr-Co-Steel	Heat Analysis	Product Analysis
1	Ni	35.00-39.00	34.70-39.30
2	Co	18.00-22.00	17.75-22.25
3	Cr	16.00-22.00	15.75-20.25
4	Ti	2.50-3.00	2.43-3.07
5	Mo	2.50-3.50	2.40-3.60
6	B	0.001-0.01	0.001-0.012
7	Si	1.50(Max)	1.6
8	Mn	1.00(Max)	1.03
9	Al	0.25(Max)	0.3
10	C	0.08(Max)	0.09
11	P	0.030(Max)	0.035
12	S	0.030(Max)	0.035

4. EXPERIMENTS

The experimental work which is consisting of L9 orthogonal array based on Taguchi design. The orthogonal array reduces the total number of experiments. In this experimental work total numbers of runs are 9. Experimental setup, selection of work piece and tool, experimental procedure and taking all the value and calculation of MRR are explained below.

Experiments were conducted by using the machining setup. The control parameters like Voltage (V), discharge current (Ip) and pulse duration (Ton) were varied to conduct 9 different experiments and the weights of the work piece before machining and after machining by using balancing machine were taken for calculation of MRR.

Fig. 3. Experimental Set-up

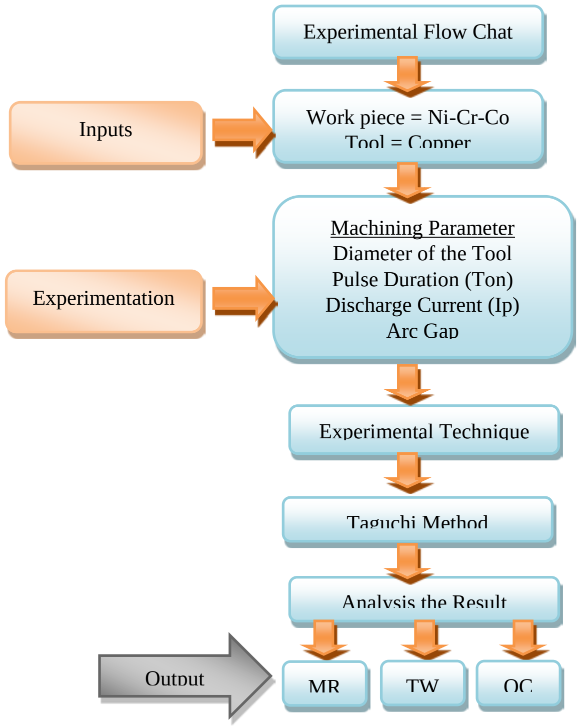

Fig. 4. Experimental Flow Chart

5. TAGUCHI METHOD

The Taguchi methods are statistical methods created by Genichi Taguchi to enhance the quality of manufactured goods, and more recently is also applied to engineering, biotechnology, marketing and advertising. However, Taguchi recognized techniques for distinguishing those noise sources that have the greatest effects on product variance. His thoughts have been received by successful manufacturers around the globe because of their results in creating superior production processes at much lower costs.

A. Quality of Taguchi Method

Quality has been defined by many as; "zero defects" or “customer satisfaction." Taguchi proposes an all-encompassing perspective of value which relates quality to cost, not just to the manufacturer at the time of production [11]. Taguchi defines quality as:

> "The quality of a product is the (minimum) loss imparted by the product to society from the time product is shipped” [8].

B. Taguchi's Approach to Parameter Design

Taguchi's approach to parameter design provides the design engineer with a precise and effective technique for determining near optimum design parameters for performance and cost [9]. The objective is to select the best combination of control parameters so that the product or process is most robust with respect to commotion factors.

The Taguchi technique uses orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. Utilizing orthogonal arrays significantly decreases the number of experimental configurations to be studied. Moreover, the conclusions drawn from small scale experiments are valid over the whole experimental region spanned by the control factors and their settings, orthogonal arrays are not unique to Taguchi [10]. In this array, the columns are commonly orthogonal. That is, for any pair of columns, all combinations of factor levels occur, and an equivalent number of times. Here there are four parameters A, B, C, and D, each at three levels. This is called an "L 9" design, with the 9 showing the nine rows, configurations, or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus, L 9 means that nine experiments are to be completed to consider four factors at three levels.

TABLE II. L9 (3^4) ORTHOGONAL ARRAY

Sr. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
8	3	2	1	3
9	3	3	2	1

The number of columns of an array represents the maximum number of parameters that can be observed using that array. Note that this design reduces 81(3^4) configurations to nine experimental evaluations. There are greater savings in testing for the larger arrays. For example, using an L27 array, 13 parameters can be learned at three levels by running only 27 experiments instead of 1,594,323(3^{13}). The Taguchi method can reduce research and development costs by improving the efficiency of creating information needed to design systems that are insensitive to utilization conditions, manufacturing variation, and deterioration of parts. As a result, development time can be shortened significantly, and important design parameters affecting operation, performance, and cost can be recognized. Moreover, thus manufacturing and operations expenses can also be greatly reduced.

C. Design the Matrix Experiment and Define the Data Analysis

The next step is to design the matrix experiment and define the data analysis strategy. First, the appropriate orthogonal arrays for the noise and control parameters to fit a specific study are chosen. Taguchi gives numerous standard orthogonal arrays and corresponding linear graphs for this purpose A typical approach is the utilization of Monte Carlo simulation [9]. However, for an accurate estimation of the mean and variance, Monte Carlo simulation requires a large number of testing conditions which can be costly and time consuming. As an alternative, Taguchi proposes orthogonal array based simulation to evaluate the mean and the variance of a product's response resulting from variations in noise factors [9]. With this approach, orthogonal arrays are used to sample the domain of noise factors. The diversity of noise factors are studied by crossing the orthogonal array of control factors by an orthogonal array of noise factors [7].

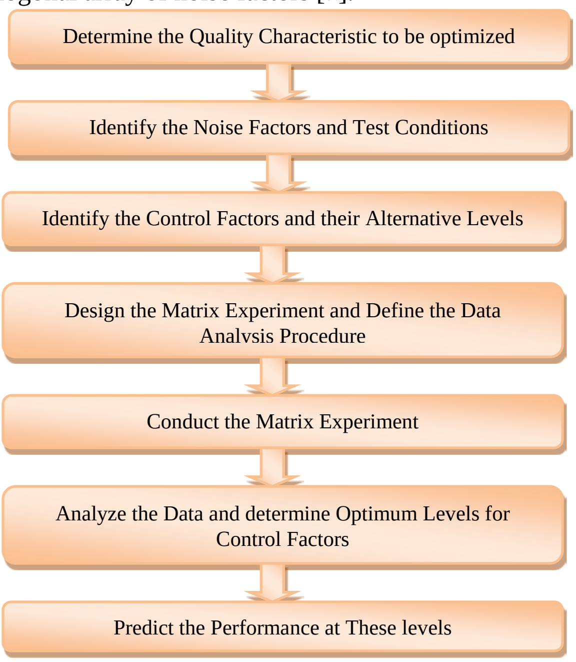

Fig. 5. Taguchi Method Flow Chart

TABLE III. NOISE ORTHOGONAL ARRAY

Sr. No.	1	2	3	4
N_1	1	1	2	2
N_2	1	2	1	2
N_3	1	**2**	2	1

D. Matrix Experiment

The next step is to conduct the matrix experiment and record the outcomes. The Taguchi method can be used in any situation where there is a controllable procedure [11].

E. Analyze the Data and Determine the Optimum Levels

After the experiments have been conducted, the optimal test parameter configuration within the experiment design must be determined. To analyze the outcomes, the Taguchi method uses a statistical measure of performance called the signal to noise (S/N) ratio borrowed from the electrical control theory [9]. The S/N ratio developed by Dr. Taguchi is a performance measure to choose control levels that best adapt with noise [7]. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the foundation for the quality characteristic to be optimized. While there are many different possible S/N ratios, three of them are considered standard and are generally applicable in the circumstances underneath [5].

- Biggest-is-better quality characteristic (strength, yield);
- Smallest-is-better quality characteristic (contamination);
- Nominal-is-best quality characteristic (dimension).

Nominal is Best: $SN_N = 10\log\left(\frac{y^{-2}}{s^2}\right)$ (2)

Larger is better: $SN_L = -10\log\left(\frac{\sum_{i=1}^{n} 1/y_i^2}{n}\right)$ (3)

Smaller is better: $SN_S = -10\log\left(\frac{\sum_{i=1}^{n} y_i^2}{n}\right)$ (4)

where y is the mean of observed data, s is the variance of y, n is the number of observations and y is the observed data.

6. Analysis of Variance (ANOVA) & Minitab

A. Analysis of Variance (ANOVA)

ANOVA is a statistically based, objective decision-making tool for recognizing any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as:

$$SS_T = \sum_{i=1}^{N}(n_i - m)^2 \quad (5)$$

Where n is the number of experiments in the orthogonal array and m is the mean S/N ratio for the ith experiment. The percentage contribution P can be calculated as:

$$P = \frac{SS_d}{SS_T} \quad (6)$$

Where,
SS_d - sum of the squared deviations.

B. Minitab

MINITAB gives both static and dynamic reaction experiments in a static response experiment; the quality characteristic of interest has a fixed level. The objective of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors [4]. MINITAB calculates response tables and generates the main effects and interaction plots for:

- Signal-to-noise ratios (S/N ratios) vs. the control factors.
- Means (static design) vs. the control factors.

DOE (design of experiments) helps to investigate the effects of the input variables (factors) on an output variable (response) at the mean time. These experiments consist of a series of runs, or tests, in which purposeful changes are made to the input variables. Information is gathered at each run. DOE is utilized to distinguish the procedure conditions and product components that affect quality, and then determine the factor settings that optimize results.

C. Taguchi Design Experiments in MINITAB

A Taguchi design is a designed experiment that lets you choose a product or process that functions more consistently in the working condition. Taguchi designs recognize that not all factors that cause variability can be controlled. These uncontrollable factors are called noise factors. Taguchi designs try to identify controllable factors (control factors) that minimize the effect of the noise factors. During experimentation, you manipulate noise factors to force variability to occur and then determine optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used.

Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. An orthogonal array means the design is balanced so that factor levels are weighted similarly. Because of this, each factor can be evaluated independently of all the other factors, so the impact of one factor does not affect the estimation of an alternate factor. This can reduce the time and cost associated with the experiment when fractionated designs are utilized.

TABLE IV. DESIGN METRIX

Sr. No.	Machining Parameter	Symbol	Unit	Level		
				Level 1	*Level 2*	*Level 3*
1	Electrode C/S Area	A	mm2	**9.5**	**9.5**	**12.40**
2	Spark on Time	Ton	μs	**100**	**250**	**400**
3	Discharge Current	Ip	A	**10**	**20**	**30**

The three factors mixed level setup is chosen with a total of 18 experiments to have been conducted, and hence, the OA L_{18} was chosen [6]. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L_{18} setup, which in turn would reduce the number of experiments at the later stage. In addition, a comparison of the results would be simpler [8]. The levels of experiment parameters electrode cross section area (A), spark on time (T_{on}), and discharge current (I_p), are shown in Table V and the design matrix is depicted in Table VI.

TABLE V. OBSERVATION TABLE

Sr. No.	Area	Ip (A)	Ton (µs)	Wt of Work piece(gm) Wjb	Wt of Tool (gm) Djt	Wt b	Cavity C/S (mm) Wta
1	9.50*9.50	10	100	150.13	9.94*9.94	5.42	5.39
2	9.50*9.50	10	250	150.10	9.99*9.99	5.39	5.38
3	9.50*9.50	10	400	147.84	9.76*9.76	5.38	5.37
4	9.50*9.50	20	100	145.61	9.58*9.58	5.37	5.33
5	9.50*9.50	20	250	143.44	9.61*9.61	5.33	5.32
6	9.50*9.50	20	400	141.26	9.86*9.86	5.32	5.30
7	9.50*9.50	30	100	138.39	9.77*9.77	5.30	5.22
8	9.50*9.50	30	250	136.29	9.80*9.80	5.22	5.19
9	9.50*9.50	30	400	134.09	9.68*9.68	5.19	5.18
10	12.40*12.40	10	100	223.18	12.89*12.89	12.90	12.88
11	12.40*12.40	10	250	219.28	12.96*12.96	12.88	12.87
12	12.40*12.40	10	400	215.35	13.00*13.00	12.87	12.86
13	12.40*12.40	20	100	211.39	12.95*12.95	12.86	12.82
14	12.40*12.40	20	250	207.59	12.92*12.92	12.82	12.81
15	12.40*12.40	20	400	203.98	12.99*12.99	12.81	12.76
16	12.40*12.40	30	100	226.58	13.00*13.00	12.76	12.70
17	12.40*12.40	30	250	222.82	13.01*13.01	12.70	12.67
18	12.40*12.40	30	400	219.00	13.04*13.04	12.67	12.65

D. Design Matrix and Observation Table

Ni-Cr-Co steel material particulate used a square shape of Copper tube tool with the dimensions of 9.5*9.5 mm2 and 12.40*12.40 mm2. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94 °C) was utilized as the dielectric fluid. In this experiment, voltage and duty cycle are kept constant at 100 v and six, respectively. For the study, three factors are tackled with a total number of 18 tests performed on die sinking EDM. The calculation of the material removal rate and tool wear rate was carried out using a digital weight machine. This machine limit is 300 gm.

7. RESULT & DISCUSSION

A. Influence on MRR, TWR & OC

The S/N ratios for MRR are calculated, as below mention formula. The Taguchi method is used to analyze the results of the response of the machining parameter for the larger is better criteria.

$$\text{Larger is better: } SN_L = -10\log\left(\frac{\sum_{i=1}^{n} 1/y_i^2}{n}\right) \quad (7)$$

The S/N ratios for TWR & OC are calculated, as shown in the formula below. The Taguchi method is used to analyze the results of the response of the machining parameter for the smaller is better criteria.

$$\text{Smaller is better: } SN_S = -10\log\left(\frac{\sum_{i=1}^{n} y_i^2}{n}\right) \quad (8)$$

8. ANOVA FOR MRR

The analysis of variances for the factors are shown in Table VII, which clearly indicates that T_{on} of the tool is not important for influencing MRR and the Ip and Area are the most influencing factors for MRR. The delta values are Area of tool, Ton and Ip are **1.22, 0.73, 10.02**, respectively, depicted in Table IX.

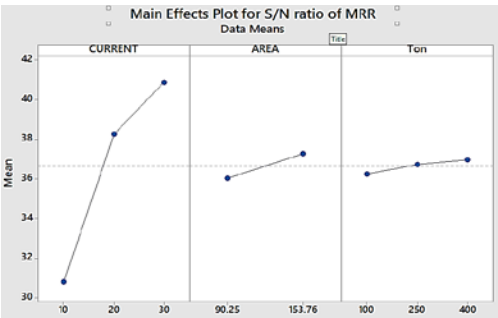

Fig. 6. Main Effect plot for S/N ratio of MRR

During the process of electrical discharge machining, the impact of various machining parameters like Ip, Ton and Area of tool has critical impact on MRR, as shown in fig the main effect plot for the S/N ratio of MRR in Fig. 6 The discharge current (Ip) is directly proportional to MRR in the range of 10A to 20A. This is expected because an increase in pulse current produces strong sparks, which create the higher temperature, making more material to melt and erode from the work piece. Also, obviously clear that the other factor does not influence as much compared to Ip. But, with the increase in discharge current from 20A to 30A, MRR increases slightly. Moreover, MRR decreases monotonically with the increase in pulse on time [3]. The response table for MRR, TWR is shown along with the input factors.

TABLE VI. RESPONSE TABLE

Run	Area (mm^2)	Ip (A)	Ton (µs)	MRR (mm^3/min)	MRR (gm/min)	OC (mm)
1	9.50*9.50	10	100	43.85	0.003508	0.223
2	9.50*9.50	10	250	34.62	0.001225	0.255
3	9.50*9.50	10	400	30.46	0.001092	0.145
4	9.50*9.50	20	100	65.57	0.009661	0.062
5	9.50*9.50	20	250	67.61	0.002481	0.085
6	9.50*9.50	20	400	79.06	0.006024	0.221
7	9.50*9.50	30	100	82.84	0.020962	0.190
8	9.50*9.50	30	250	109.56	0.011673	0.450
9	9.50*9.50	30	400	111.55	0.003891	0.165
10	12.40*12.40	10	100	29.68	0.001218	0.245
11	12.40*12.40	10	250	34.66	0.000705	0.284
12	12.40*12.40	10	400	37.21	0.007577	0.315
13	12.40*12.40	20	100	89.96	0.002207	0.295
14	12.40*12.40	20	250	99.61	0.009615	0.290
15	12.40*12.40	20	400	95.19	0.014962	0.335
16	12.40*12.40	30	100	117.20	0.007334	0.345
17	12.40*12.40	30	250	116.74	0.004987	0.360
18	12.40*12.40	30	400	129.68	0.001169	0.390

TABLE VII. THE S/N RATIO FOR MRR, TWR & OC

Sr. No.	Current	Area	Ton	MRR	TWR	OC	S/N TWR	S/N TWR	S/N OC
1	*10*	9.50*9.50	100	43.85	0.003508	0.223	58.64371	32.83939	13.0339
2	*10*	9.50*9.50	250	34.62	0.001225	0.255	58.23728	30.78654	11.8692
3	*10*	9.50*9.50	400	30.46	0.001092	0.145	59.23555	29.6746	16.77264
4	*20*	9.50*9.50	100	65.57	0.009661	0.062	40.29497	36.3341	24.15217
5	*20*	9.50*9.50	250	67.61	0.002481	0.085	52.10746	36.60022	21.41162
6	*20*	9.50*9.50	400	79.06	0.006024	0.221	44.4023	37.95914	13.11215
7	*30*	9.50*9.50	100	82.84	0.020962	0.190	32.05511	38.3648	14.42493
8	*30*	9.50*9.50	250	109.56	0.011673	0.450	38.65628	40.79304	6.93575
9	*30*	9.50*9.50	400	111.55	0.003891	0.165	48.19878	40.94939	15.65032
10	*10*	12.40*12.40	100	29.68	0.001218	0.245	58.28705	29.44928	12.21668
11	*10*	12.40*12.40	250	34.66	0.000705	0.284	63.03622	30.79657	10.93363
12	*10*	12.40*12.40	400	37.21	0.007577	0.315	62.47795	31.41319	10.03379
13	*20*	12.40*12.40	100	89.96	0.002207	0.295	42.41005	39.08099	10.60356
14	*20*	12.40*12.40	250	99.61	0.009615	0.290	53.12395	39.96606	10.75204
15	*20*	12.40*12.40	400	95.19	0.014962	0.335	40.34101	39.57183	9.499104
16	*30*	12.40*12.40	100	117.20	0.007334	0.345	36.50021	41.37855	9.370422
17	*30*	12.40*12.40	250	116.74	0.004987	0.360	42.67544	41.34439	8.87395
18	*30*	12.40*12.40	400	129.68	0.001169	0.390	46.04321	42.25746	8.178708

9. ANOVA FOR TWR

The analysis of the variances for the factors are Area, Ip Ton, as shown in Table X, clearly indicates that the Area of the tool is not important in influencing TWR and the value of Ip and Ton most effected the TWR. The delta values for Area of tool, Ip and Ton are **0.27, 3.45 and 1.30**, respectively, as shown in Table XI

TABLE VIII. ANALYSIS OF VARIANCE FOR S/N RATION OF MRR

Sr.No.	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	Current	2	301.282	301.283	97.56	0.000
2	*Area*	2	6.670	6.670	2.16	0.164
3	*Ton*	2	1.598	1.598	0.52	0.484
4	*Error*	2	43.233	3.088	97.56	0.000
5	*Total*	8	352.783	312.639	197.8	

TABLE IX. S/N RATIO FOR MRR OF RESPONSE

Sr. No.	Level	Current	Area	Ton
1	1	30.83	36.03	36.24
2	*2*	38.25	37.25	36.71
3	*3*	40.85		36.97
4	***DALTA***	**10.02**	**1.22**	**0.73**
5	*RANK*	1	2	3

TABLE X. ANOVA FOR S/N RATIO OF TWR

Sr.No.	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	Current	2	1117.25	1117.25	41.89	0.000
2	*Area*	2	9.48	9.48	0.36	0.561
3	*Ton*	2	88.06	88.06	3.30	0.091
4	*Error*	2	373.41	26.67		0.000
5	***Total***	8	1588.21	1117.25		

TABLE XI. RESULT OF S/N RATIO SMALLER ID BETTER

Sr. No.	Level	Current	Area	Ton
1	1	-35.56	-33.45	-32.78
2	*2*	-33.09	-33.72	-34.08
3	*3*	-32.11		-33.89
4	***DALTA***	**3.45**	**0.27**	**1.30**
5	*RANK*	1	3	2

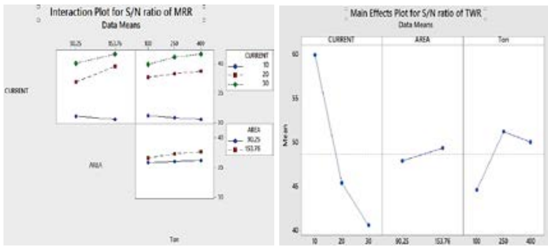

Fig. 7. (a) Interaction Plot (b) main effect plot for S/N ratio of MRR

10. ANOVA FOR OC

The analysis of variances for the factors are Area, Ip, Ton, as shown in Table V, clearly indicates that the value of Ip is most influencing on OC and also Area of tool is significant. The delta values for Area of tool, Ip and Ton are 3.21, 2.80, 1.59, respectively, as shown in Table VI.

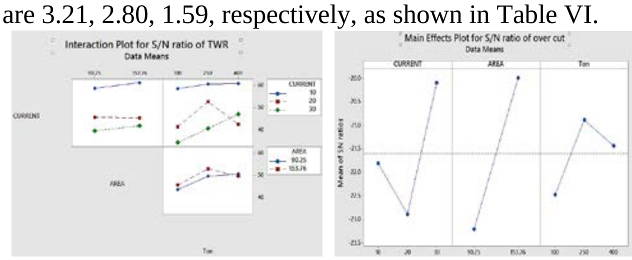

Fig. 8. (a) Interaction Plot (b) main effect polt for S/N ratio of OC

The over cut between the dimension of the electrode and the size of the cavity it is innate to the EDM procedure which is unavoidable though adequate compensation are provided at the tool design. To achieve the accuracy, minimization of over cut is essential. Accordingly, factors affecting of over cut is essential to recognize. The over cut are effect to each parameter such as Area of tool, discharge current and pulse on time, the main effect plot for S/N ratios shown by Fig. 10 for over cut. This graphs are represent the Area of tool is directly proportional to the over cut. Expanding in the discharge current from 10 to 20 A the OC is decreasing, with increase in discharge current from 20A to 30A the OC increasing slightly. Whereas, OC increases monotonically with the increase in pulse on time because which is responsible for production of spark of tool and work piece interface. The interaction plot of OC is shown in Fig. 11 where each plot exhibits the interaction between three different machining parameters like Ip, Ton and Area of the tool. This infers that the effect of one factor is dependent upon another factor. It is also confirmed by ANOVA in Table XIII.

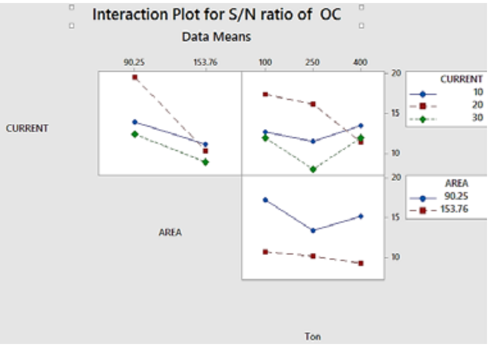

Fig. 9. Interation Plot for S/N ratio of OC

TABLE XII. ANOVA FOR S/N RATIO OF OC

Sr. No.	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	Current	2	10.879	10.879	0.75	0.400
2	*Area*	2	122.205	122.205	8.46	0.011
3	*Ton*	2	9.284	9.284	0.64	0.436
4	*Error*	2	202.172	14.441		
5	***Total***	8	344.540			

TABLE XIII. RESPONSE TABLE FOR S/N RATIO

Sr. No.	Level	Current	Area	Ton
1	*1*	*-21.80*	-23.20	-22.47
2	*2*	*-22.89*	-19.99	-20.88
3	*3*	-20.09		-21.43
4	*DALTA*	2.80	3.21	1.59
5	*RANK*	2	1	3

11. CONCLUSION

The impact of machining responses are MRR, TWR and OC of Ni-Cr-CO steel components using the Cu tool with an internal flushing system tool have been investigated for the EDM process. The experiments were conducted under various parameters setting of Discharge Current (Ip), Pulse On-Time (Ton), and Area of the tool. L18 OA based on the Taguchi design was performed for Minitab software was used to analyze the results and these responses were partially validated experimentally. The findings of the results show that the MRR discharge current is the most influencing factor, and then pulse duration time, and lastly, the diameter of the tool. The MRR increased with the discharge current (Ip). As pulse duration is extended, MRR decreases monotonically. In the case of the tool wear rate, the most important factor is the discharge current, then pulse on time, followed by diameter of tool. In the case of over cut, the most important factor is the Area of the tool, then the discharge current and then pulse on time.

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